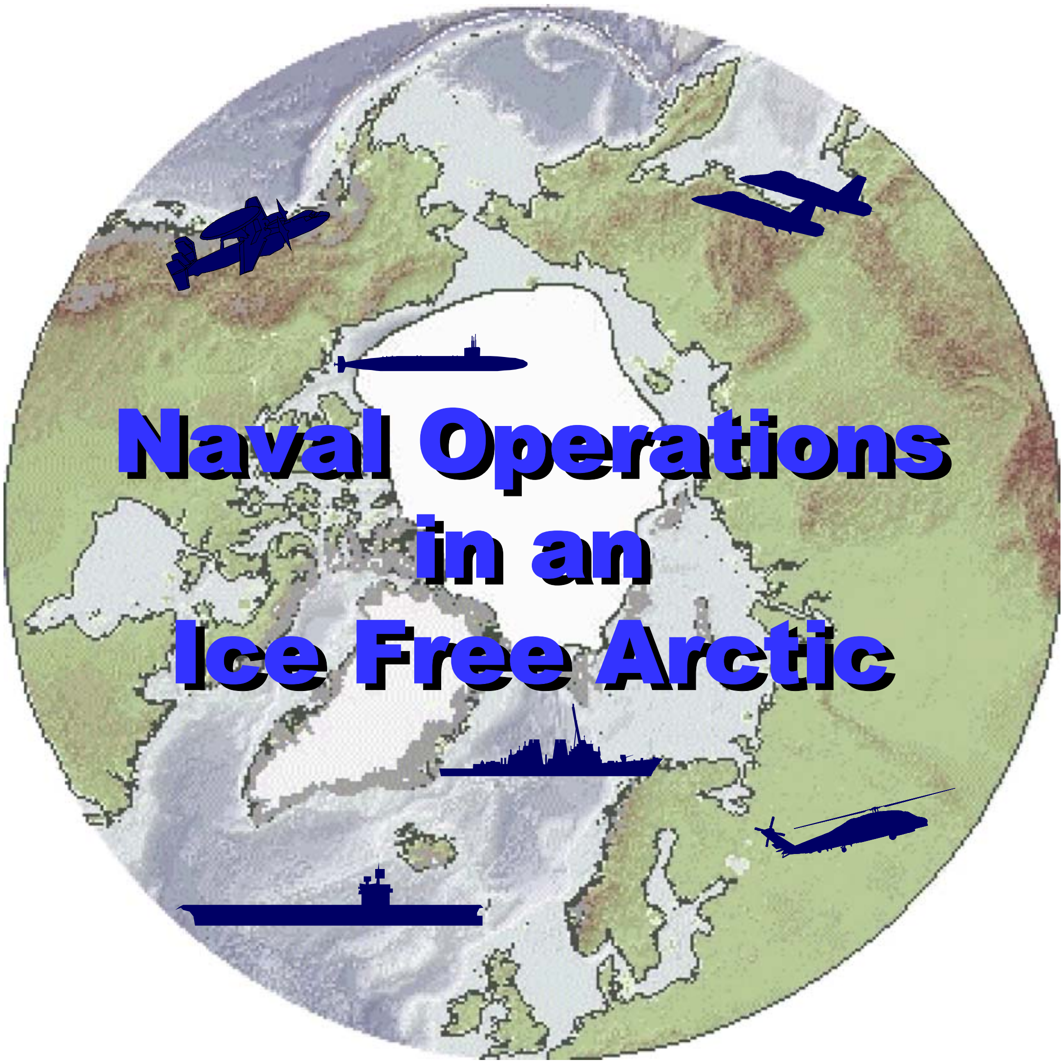

Naval Operations in an Ice Free Arctic Symposium

Handbook

17-18 April 2001

**OFFICE OF NAVAL RESEARCH,
NAVAL ICE CENTER,
OCEANOGRAPHER OF THE NAVY,
AND THE ARCTIC RESEARCH COMMISSION**

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TABLE OF CONTENTS

1. INTRODUCTION

1.1 Background

Recent news articles have highlighted the decreasing thickness and coverage of the Arctic ice cap due to global warming. Data from the National Ice Center (NIC)/Naval Ice Center (NAVICE) and U.S. submarines provide evidence of diminished summer ice coverage in the Arctic, and scientific models are consistently suggesting summertime *disappearance* of the Arctic ice cap by 2050. Seasonal sea lanes are likely to appear much sooner, requiring the Navy to expand operations in the Arctic well before 2050 – within the strategic planning window for the "Navy after next".

Some significant projections include the following:

- Over the next 20 years, the volume of Arctic sea ice will further decrease approximately 40%, and the lateral extent of sea ice will be sharply reduced (at least 20%) in summer.
- Polar low pressure systems will become more common and boundary layer forced convection will increase mixed (ice-water) precipitation. Cloudiness will increase, extending the summer cloudy regime with earlier onset and later decline. The likelihood of freezing mist and drizzle will increase, along with increased vessel and aircraft icing.
- Sonar operations in the Arctic will experience increased ambient noise levels and the surface duct will be diminished or lost. Ice keels will be shallower and less abundant and the area in which they can be expected to occur will be reduced. Active sonar detection of submarines will become more feasible.
- Within five years, the Northern Sea Route (a.k.a. the Northeast Passage) will be open to non-ice-strengthened vessels for at least two months each summer.
- Within 5-10 years, the Northwest Passage will be open to non-ice-strengthened vessels for at least one month each summer.
- Both Russia and Canada assert policies holding navigable straits in the NSR and Northwest Passage under their exclusive control. The United State differs in its interpretation of the status of these straits, with a potential for conflict.
- Within 5-10 years, potentially the Sea of Okhotsk and the Sea of Japan will remain ice free throughout the year.

This phenomenon will present unique strategic and operational challenges to U.S. Naval forces. Areas of concern include policy and strategy considerations; potential missions; and the ramifications of Arctic environmental conditions on future operations, including platform, sensor, and weapons systems design.

An initial meeting was held at the Naval Ice Center on 7 July, 2000 with representatives from NIC, the Oceanographer of the Navy (N096), Office of Naval Research (ONR), MEDEA, the Arctic Research Commission, and U.S. Coast Guard in which the national and strategic issues surrounding operations in an ice free, or ice-diminished Arctic were framed. It was recommended that a forum be established to evaluate the Naval implications of operating in an ice free Arctic. This symposium is that first step in evaluating the implications of an ice-diminished Arctic for future Navy missions and capabilities.

1.2 Purpose

The purpose of the symposium is to bring warfighters, concept and force developers, and members of the scientific community together to identify future Naval requirements for operations in an ice-diminished Arctic. Output from the symposium will provide initial guidance in determining potential naval missions and required future operational capabilities in the Arctic region.

1.3 Objectives

A. Identify potential requirements for future naval operations for an assumed projected retreat of the Arctic ice cover.
B. Examine potential impacts/effects on such operations and identify baseline capabilities for operating in this altered arctic environment.
C. Explore the strategic and policy issues that could elicit a strategic (military) response due to the arctic being ice free during a portion of the year.
D. Establish the criteria and key elements for a continuum of heightened awareness and participation in examining operations in this altered Arctic environment.

2. SYMPOSIUM STRUCTURE & METHODOLOGY

2.1 SYMPOSIUM CONCEPT

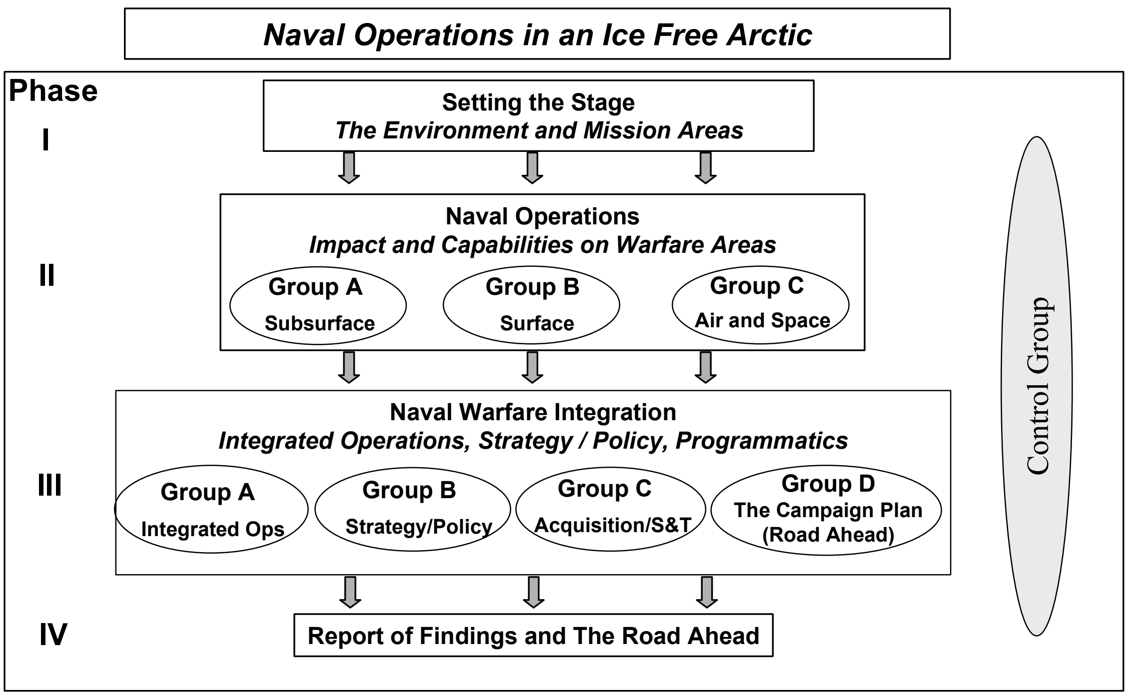
A two-day symposium is planned for 17-18 April 2001 and will be conducted at Building 22, Washington Navy Yard, Washington, DC.

The symposium will involve approximately 50 05/06 level military/civilian participants from all codes of the Navy staff, fleet representatives, program managers, U.S. Coast Guard operators, and Arctic subject matter experts. Canadian military and civilian experts and officers from the Royal Navy will achieve international representation. Warfighter participation is essential as is attendance by requirements and acquisition program management professionals since these challenges may impact the design of future weapons systems and how they are used. Discussions will be conducted at up to the SECRET releasable Canada/U.K. classification level.

During the conduct of the symposium, participants will be required to assess their needs against operationally driven requirements, identifying and documenting shortfalls and limitations and their impact on operating in an ice free Arctic. Facilitators will lead discussion sessions, and decision support software will be used to assist in discussing, clarifying, and refining identified strategies, operational impacts and required capabilities.

2.2 SYMPOSIUM STRUCTURE

The following graphic depiction and accompanying description summarizes the sequence of events for the symposium:



Note: For Phase III new focus groups are formed w/cross pollinated pers from original Phase II groups

Phase I

- An introductory session will include welcoming / introductory briefings and other presentations which will establish the context and framework for the rest of the symposium.

Phase II

- Participants will initially break into three *Interest Track Focus Groups*:

  a) Aviation Group—will address issues concerning operating aircraft in the altered Arctic environment to include fixed wing, rotary wing and UAVs.

b) Surface Group—will address issues concerning the operation of Naval surface vessels in the altered Arctic environment.

c) Subsurface Group— will address issues concerning the operation of submarines and undersea warfare in the altered Arctic environment.

- In three sequential sessions, these groups will examine the operational roles and missions likely to be undertaken in the Arctic, then identify and discuss the unique operational challenges and threats presented in accomplishing those missions, and finally determine the capabilities needed to meet those challenges.

- Intel/C4I/METOC/Geospatial Information & Services (GI&S)/Logistics will be discussed across all panels.

- The groups will then meet in plenary session to brief out their particular findings.

Phase III

- Participants will be reformed into four new *Interest Track Focus Groups:*
  a) Integrated Operations Group – will consider the operational implications and capabilities from a Battle Group/fleet presence perspective vice platform.
  b) Strategy and Policy Group – will consider the Naval strategy and policy to achieve operational presence and success in the Arctic.
  c) Acquisition / Science & Technology Group – will consider appropriate methods for inserting capabilities discussed into the formal requirements and acquisition process, and the integration of new technologies.
  d) Campaign Plan Group – will begin to build the "road ahead" plan for continuing the dialogue of the symposium.

- The groups will then meet in plenary session to brief out their particular findings.

Phase IV

- The symposium will conclude with a final plenary session to summarize the key initial symposium findings and review options for furthering the discussion in the future.

The Control Group, consisting of the NAVICE, ONR, Oceanographer of the Navy, Arctic Research Commission and WBB personnel, will oversee execution of the entire symposium and also serve to handle a number of requirements. This group will: (a) look for commonalties among the focus groups as they deal with their situations; (b) assist the groups by providing subject matter expertise when needed; (c) attempt to discern if there may be issues that warrant further exploration; and (d) work during the event to structure the final session.

2.3 SYMPOSIUM PROCESS AND GUIDANCE

PHASE I: Welcome / Introduction / Lead-in Speakers

This session will begin at 0800 Tuesday morning following check-in and will continue until about 1010. The session will include welcoming and administrative remarks, a keynote address by RADM Bowler, N70, and several other presentations designed to establish a foundation for the rest of the event.

PHASE II: Naval Operations: Impact and Capabilities on Warfare Areas

Session 1: Opportunities and Threats

At approximately 1020, participants will assemble for the first time in their three seminar rooms. The first part of this meeting -- about 20 minutes -- will be used for introductory and organizational purposes, and teaching the use of the collaborative software that will be used to brainstorm and capture ideas.

The rest of this session -- which will run from 1020 until 1200 is designed to help participants develop a general understanding of the future roles and missions of naval forces in the altered Arctic. The primary focus of this session will be to discuss alternative missions and tasks for naval forces in the altered Arctic and the potential threats that might be encountered. Presentations in plenary session and group discussions in the seminar groups will be employed to achieve the objectives of this session.

This examination will be conducted from the perspective of the particular functional area assignment of the seminar group.

The following questions will be used to focus the groups' efforts in working through the main issues associated with this session.

From the <u>perspective of its assigned functional area</u>:

- *Considering what you have just heard concerning the projected environmental changes in the Arctic and their potential impact on Naval Operations, from your group's platform-specific operational perspective, what comments do you have, or alternatives for missions/tasks can you offer for operations in the Arctic in the 2015-2020 timeframe?*

Example: *Is it envisioned that a Surface Action Group would transit the Northwest Passage to move from operations in the Atlantic to operations in the Pacific?*

<u>Session 2:</u> Operational Implications

This session -- which will run from 1215 until 1400 (including a working lunch) -- is designed to allow the participants to develop a general understanding of the operational implications of the future roles and missions of naval forces in the altered Arctic that were discussed in Session 1. The primary focus of this session will be to discuss and develop a list of unique operational challenges and threats to accomplishing these missions that may be present in that environment. Presentations in plenary session and group discussions in the seminar groups will be employed to achieve the objectives of this session.

The following questions will be used to focus the groups' efforts in working through the main issues associated with this session.

From the <u>perspective of its assigned functional area</u>:

- *What unique operational challenges to accomplishing these missions are presented in that environment?*

__Example:__ For the Aviation Group, what will be the likely challenges to carrier flight deck operations in an Arctic environment of sub-zero temperatures, icing and occasional heavy fog?

<u>Session 3:</u> Capabilities Required

This session -- which will run from 1400 until 1600 is designed to develop a set of capabilities needed to meet the challenges that were discussed in Session 2. The principal input to this session is the list of shortfalls/needs -- developed by each seminar during the previous session.

The following questions will be used to focus each group's discussions in working through the main issues associated with this session.

From the <u>perspective of its assigned functional area</u>:

- *What are the capabilities needed to meet those challenges addressed in Session 2?*
    - *What changes in your group's warfare area platforms (including design, sensors, weapons, communications, navigation, etc) would these operations in the projected environment of the Arctic in the 2015-2020 timeframe require?*
    - *What changes in platform-specific tactics, operating procedures, and support would be required to operate in the Arctic in the 2015-2020 timeframe? What would be the implications, if any, on op tempo, basing, etc.?*

<u>Session 4:</u> Capability Shortfalls

This session -- which will run from 1400 until 1600 is designed to develop the shortfalls in current programs to the required capabilities addressed in Session 3. The principal input to this session is the list of capabilities -- developed by each seminar during the previous session.

The following questions will be used to focus each group's discussions in working through the main issues associated with this session.

From the <u>perspective of its assigned functional area</u>:

- *Based on the capabilities needed that were discussed in the previous session, what are our current shortfalls for operating in this environment?*

Phase Deliverables: Plenary session briefout 0800 Day 2 (Wednesday)

- *Each group is tasked to produce a 15-minute PowerPoint slide briefing summarizing its principal findings from this session. The briefing format will be as follows:*
    - *Naval missions considerations*
    - *Operational challenges*
    - *Capabilities required*
    - *Capability shortfalls*

PHASE III: Naval Warfare Integration

This phase will run from 0945 – 1430 the entire second day (including working lunch). Participants will be divided up into four new *Interest Track Focus Groups:* Integrated Operations Group; Strategy and Policy Group; Acquisition / Science & Technology Group; and Campaign Plan Group. These groups will be cross-pollinated with participants from the previous warfare specific groups and collaborative software will be used to brainstorm and capture ideas. The purpose of this phase is to address some of the larger concerns of naval operations in the Arctic having to do with integrated naval operations, programmatics and policy issues. Seminars will maintain their specific interest area focus throughout this session.

The principal input to this session is the discussions and output from Phase I and 2.

Each of these groups will be tasked with examining specific issues from their particular perspective as follows:

<u>Integrated Ops Group</u>:

* *Based on the outputs from phases I & II (warfare area specific), are there any additional missions or integrated naval operations that would be required in the Arctic in the 2015-2020 timeframe?*

* *What changes in CVBG, ARG, or SAG tactics, operating procedures and support would be required to operate in the Arctic in the 2015-2020 timeframe? What theater or national asset support requirements would be required?*

* *What would be the implications, if any, on op tempo, basing, etc.?*

* *What are the capabilities needed to meet those challenges and shortfalls addressed in Phase II?*

Strategy & Policy Group:

* *How might our national and maritime strategies change as a result of the projected Arctic changes? What would be the implications of those strategy changes on naval missions and operations in the Arctic? On force structure? On basing requirements and op tempo?*

* *Are there any additional shortfalls to those addressed in Session 2? What new capabilities or policy changes would be needed to meet the challenges of naval operations in the Arctic in the 2015-2020 timeframe?*

Programmatics (Acquisition/S&T) Group:

* *Based on the outputs from sessions 1 & 2 (warfare area specific), what are the implications for new acquisition programs and modifications to existing programs to support the projected naval operations in the Arctic in the 2015-2020 timeframe? What new technologies will be required?*

* *Given changing requirements to meet the changing environment, how do we ensure these are included in the IWAR / PPBS process?*
    * *What is the method for doing this? / How should this be done?*

* *The QDR doesn't talk about the Arctic. Should it? What might we want to put into QDR language?*

* *Should the Navy revive RDT&E in Arctic environments? How?*

Campaign plan Group:

- *What other factors concerning naval operations in an ice free Arctic need to be considered that were not addressed in this symposium?*
- *How might we go about looking at those?*
- *What methodologies might we want to use to do further exploration in this area?*
- *What should be the next step?*
- *…. and the next step after that?*

Phase Deliverables: Plenary session briefout 1430 Day 2, Wednesday

- *Each group is tasked to produce a 15-minute PowerPoint slide briefing summarizing its principal findings from this session. The briefing format will be as follows:*
    - *Top 4-5 critical issues*
    - *Capabilities or requirements identified*
    - *Other Issues and Concerns (operational, doctrinal, organizational, etc.)*

PHASE IV: Report of Findings

This final session will begin at 1530 Wednesday following the Phase III outbriefs. All of the symposium participants will meet in plenum and this session will encompass a summary of key symposium findings, a discussion of what the next step should be in examining operations in the altered Arctic environment (including beyond DOD), and the sponsor's closing comments.

3. DAILY SCHEDULE

Day 1, Tuesday 17 April

0800 – 0805*	Administrative Remarks	Mr. Nevitt, WBB
0805 – 0810*	Welcome Remarks	CDR Willis, NAVICE
0810 – 0820*	Introductory Remarks	RADM West, N096
0820 – 0840*	Keynote Speaker	RADM Bowler, N70
0840 – 0910*	Environmental Context	Dr. Brass, ARC
0910 – 0930*	Operational Perspective	CAPT Garrett, USCG
0930 – 0940	Break	
0940 – 1000*	Vignettes	LCDR Lamb, NAVICE
1000 – 1010*	Charge to the Participants	Mr. Nevitt
1010 – 1020	Break – Move to Seminar rooms	
1020 – 1200	Phase II, Session 1 - Opportunities and Threats	
1200 – 1215	Break - Collect lunches (working lunch)	
1215 – 1400	Phase II, Session 2 – Challenges	
1400 – 1600	Phase II, Session 3 – Capability requirements	
1600 – 1700	Phase II, Session 4 – Shortfalls	

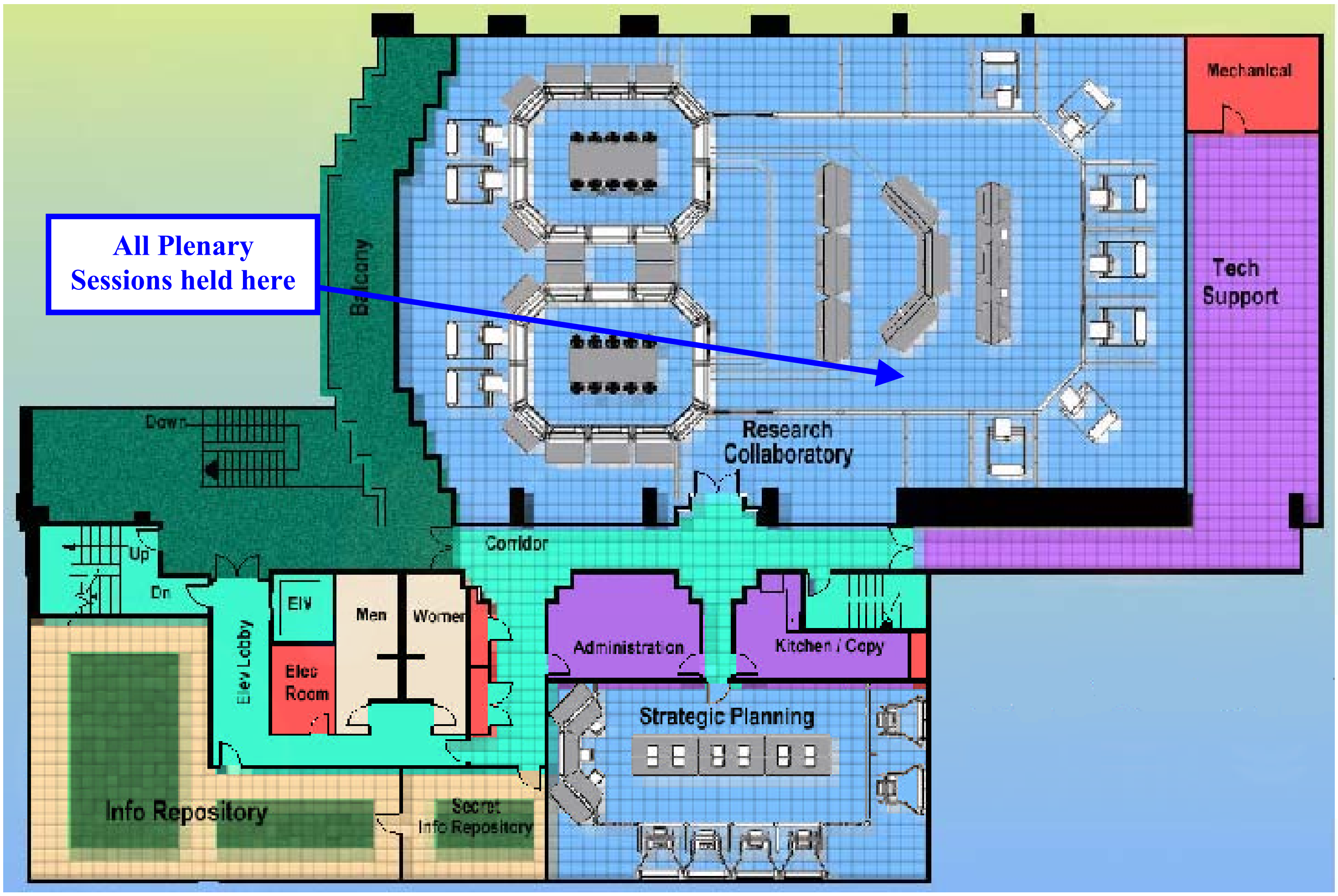
Day 2, Wednesday 18 April

0800 – 0930*	Briefout of Phase II	Group Leaders
0930 – 0945	Break – Move to Seminar rooms	
0945 – 1430	Phase III Discussions w/working lunch	
1430 – 1530*	Phase III Briefouts	Group Leaders
1530 – 1545*	Phase IV, Symposium Review	Hon. George Newton
1545 – 1600*	The Road Ahead	CDR Willis
1600 – 1615*	Closing Remarks	CDR Willis

*** Denotes session in plenary**

APPENDIX A

FACILITY MAP



Seminar groups will meet as follows:

Phase II:
Air – Front of Collaboratory
Surface – Back of Collaboratory
Subsurface – Strategic Planning Center

Phase III:
Integrated Operations Group – Front of Collaboratory
Strategy & Policy Group – Strategic Planning Center
Acquisition / S&T Group – Back of Collaboratory (Right Side)
Road Ahead Group - Back of Collaboratory (Left Side)

APPENDIX B

OPERATIONAL PERSPECTIVE – VIGNETTES

1. Freedom of Navigation (Right of Transit Passage): Northern Sea Route dispute between Russia and the U.S escalates. The legal status of the NSR has long been one of the most contentious political issues in US–Soviet/Russian Arctic relations. The US claims the ice-covered straits of the route to be international and subject to the right of transit passage, while Russia claims them as internal waters under several lines of argument, including historic waters, closed by straight baselines. Russia asserts policies holding navigable straits in the NSR under their exclusive control[1]. Although icebreaker escorts are no longer required, Russia charges a tariff for passage. European shipping companies lobby the EU to adopt a policy that accepts the tariffs, which are competitive with the Suez and Panama Canals for Pacific/Atlantic transit. The U.S. does not want the EU to set a precedent. The USN decides to conduct a FONOP (Freedom of Navigation Operation) through the NSR and sends a SAG consisting of one DDG, one DD, and one FFG to enter the NSR from the west. An LA Class SSN is also assigned to rendezvous with the SAG northeast of Iceland and conducts a submerged NSR transit in support of the SAG.

2. Battle Group Transit of Northwest Passage: Chinese sovereignty claims in the China Sea and repeated military exercises in the area lead to a confrontation with Taiwan and China. By the 2020 timeframe, China SSNs have the communications and navigation capabilities for blue water deployments. Naval forces normally forward deployed to Westpac have been sent to Persian Gulf due to a crisis there. The USS Stennis is deployed from San Diego, but Commander Seventh Fleet wants a Second CVBG at his disposal. The USS George Washington is preparing for a Med deployment to relieve the USS Truman in August. The decision is made to deploy the GW battle group to Westpac and extend the USS Truman or gap the Mediterranean Sea. The NW passage is ice free in the summer and commercial shipping routinely transits. The NW passage offers the shortest route and reduces the transit from 17500 nm around Cape Horn and 11600 nm through the Panama Canal to 8700 nm. Russian SSN crosses Arctic to intercept and monitor CVBG transit. With U.S. forces tied down in Persian Gulf, China seizes the opportunity position forces on disputed islands in China Sea. Hostilities escalate. China believes that it can prevail in an

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[1] Ostreng, W. 1999. Strategic, legal and political implications of international shipping on the NSR: A summary. The Northern Sea Route User Conference Secretariat (ed.), 1999: The Northern Sea Route User Conference - Executive Summaries. Lysaker: The Fridtjof Nansen Institute. 136 pp. http://www.fni.no/insrop/execsum.htm.

engagement with the JCS BG, and positions both SSs and an SSN in the Strait of Malacca to cut off reinforcement from the west. China perceives the U.S. threat to be the GW BG and deploys an SSN to oppose the transit through Bering Strait. The USWC requires the Bering Strait to be sanitized prior to transit.

3. Protection of Shipping: Fishing becomes big industry in the Beaufort and Chukchi Seas, and tensions rise between Russian, Japanese and U.S. fishing fleets. Russia asserts a claim on the continental shelf in the Chukchi Sea including the Chukchi Cap as a historic sea and territorial waters. The U.S. and Japan dispute Russian claims and continue to operate fishing fleets in the vicinity of Chukchi Cap. USCG aerial patrols obtain evidence of Russian vessels conducting illegal fishing inside U.S. EEZ and seize the responsible vessels. Hostile fishing activities including, cutting each nets, vessel ramming, etc. occur weekly. The single USCG Hamilton class cutter that operates north of the Bering Strait is unable to control the situation. Alaskan Senators and Representatives are demanding action from the Departments of Defense, State and Commerce. Russian Naval forces supported by air forces have moved in to protect their interests and are bullying U.S. fishing fleet, including incursions into U.S. EEZ. The USN sends two frigates and a destroyer to counter the Russian presence. A SSN is deployed for ISR and P-3s and Global Hawk UAVs from Adak, AK assist with surveillance.

4. Maritime Interdiction Operation: All source intelligence indicates that merchant shipping will be used to transport chemical warfare agents via the North West Passage on a route from China with a destination on the U.S. East Coast. US and Canadian establish MPA detachments in Adak, AK, Inuvik NW Territories and Thule, Greenland to track the vessel, but weather precludes continuous surveillance. HUMINT sources substantiate concerns that cargo may be transferred to a smaller vessel (i.e. a f/v or speedboat) in the Bering Sea or Hudson Bay as a point of entry into North America. Satellite passes are too infrequent to determine if cargo is possibly unloaded. USN coordinates with USCG and CCG to monitor possible ports. A SSN operating in the Norweigan Sea conducts an Arctic crossing to covertly intercept and track the suspect merchant vessel through the Canadian Archipelago and report on its activities.

5. Drug trafficking: Former Soviet military transports are used by organized crime activities to smuggle heroin via air routes out of Russia, across the Arctic, and into North America. JIATF North is established to maintain naval detection and monitoring assets and coast guard law enforcement assets in the Arctic. Relocatable over the horizon radar (ROTHR) sites located in Alaska and Canadian Archipelago are used in conjunction with NORAD to maintain surveillance. At least one Aegis platform is assigned continuous picket duty. USN P-3s flying out of Barrow, AK and CP-140s flying out of Inuvik, NW

Territories are used for aerial intercept and tracking. A SSN conducts an ISR mission offshore of departure airfields.

6. USW Coordinated Operation: In 2030, the U.S. has an operational Ballistic Missile Defense shield over parts of Asia. A rogue nation with chemical/biological capabilities deploys a SSBN into the Arctic to close the distance to the U.S. and take advantage of hiding in the marginal ice zone. A JTAA is established in the Chukchi and Beaufort Seas . A SAG with T-AGOS support and MPA working in the JTAA provide localization assets with a subsequent handoff to a USN SSN for tracking. A DDG capable of theater ballistic missile defense (LINEBACKER) assumes picket duty in the area in the event of a successful ballistic missile launch.

7. Non-Combatant Evacuation Operation: Environmental terrorists seize a research station in the Svalbard Archipelago being used by a U.S. based multi-national corporation for mineral and oil exploration in the Arctic. The terrorists have been using explosives to destroy equipment at the station, and are threatening personnel if the corporation does not cease all activities in the Arctic Ocean. Although Svalbard is under Norwegian sovereignty, a U.S. signed international treaty prohibits military activities in the archipelago. The breakdown of hostage negotiations is followed by the execution of some of the U.S. citizens. The USS Saipan ARG and 26th MEU, which is Special Operations Capable, are conducting an exercise off Scotland. The Saipan transits to Svalbard and plans a rescue using helo inserted special forces. EO capable P-3s flying out of Tromso, Norway conduct surveillance. U.S. military actions incite protest from the Russians.

APPENDIX C

ARCTIC OCEAN CLIMATE CHANGE

The following is an edited compilation of the views of a panel of experts convened at request of the United States Arctic Research Commission to assist the Navy in considering the effects of climate change on their operations in and around the Arctic Ocean. They were asked to contribute their informed views of the changes to be expected in the Arctic Ocean in the mid to late Twenty First Century.

Summary:

- The climate of the Arctic responds to short-term variations on a roughly decadal scale known as the Arctic Oscillation (AO) and the North Atlantic Oscillation (NAO), which are closely coupled and may be features of the same phenomena observed in different regions. These decade long oscillations will continue to add variability to Arctic climate.

- Model studies indicate that temperatures in the Arctic region will increase by mid-century with summer temperature (Jun-Aug) increasing by 1-2 deg. C, autumn (Sep-Nov) by 7-8 deg. C, winter (Dec-Feb) by 8-9 deg. C and spring (Mar-May) by about 5 deg. C. Variations between model predictions are of the order of 1-2 deg. C in summer and 5-6 deg. C in winter.

- In the winter the entire Arctic Basin will be ice covered. Model studies suggest that summer ice extent will decrease by roughly 30% and ice volume by roughly 40%. A conservative consideration of model results suggests summer ice extent will decrease by only 15% and that ice volume will decrease by 40% leading to an increase in the relative abundance of thin, first-year ice.

- The Sea of Okhotsk and the Sea of Japan will remain ice free throughout the year. The Russian coast and the Canadian Archipelago will be ice free and open to navigation by non-ice-strengthened ships in summer.

- In the atmosphere, the Arctic boundary layer will be warmer and wetter. Cloudiness will increase, extending the summer cloudy regime into earlier onset and later decline. The likelihood of freezing mist and drizzle will increase as a result.

- Polar low pressure systems will become more common and boundary layer forced convection will increase mixed phase (ice-water) precipitation. Vessel and aircraft icing will be more common.

- Arctic warming will affect permafrost. The active (seasonally melted) layer will thicken and permafrost extent in the discontinuous permafrost region (along the borders of permafrost stability) will decrease. The inner and outer boundaries of the discontinuous zone will move to the North.

- Changes in timing and composition of river runoff will affect surface seawater. Increased sediment loads in spring runoff will spread out at sea affecting optical transparency.

- Soils will be drier and more susceptible to tundra fires. Local optical properties may change affecting energy balances and local weather.

- Declines in traffic on the Northern Sea Route (NSR) may continue in concert with Russian economic difficulties. But climate induced increases in trafficability in the NSR may cause increased use for Atlantic-Pacific transportation.

- Both Russia and Canada assert policies holding navigable straits in the NSR and the Northwest Passage under their exclusive control. The US differs in their interpretation of the status of these straits. As these routes become more available for international traffic, conflicts are likely to arise.

- Ships that can expect contact with even minor abundances of sea ice require increases in stiffeners and plate thickness in the affected region. Underwater installations including propellers, rudders, fin stabilizers, sea chests and especially thin-skinned sonar installations must be redesigned for Arctic operations.

- Icing of ships and aircraft will require accommodation in ship/aircraft design and operation. Weapons systems will also be affected by icing conditions.

- Sonar operations in the Arctic will experience increased ambient noise levels and the surface duct will be diminished or lost. Ice keels will be shallower and less abundant and the area in which they can be expected to occur will be reduced. Active sonar detection of submarines will become more feasible.

- Russian economic levels have resulted in the reduction of the Russian Arctic's European population. Operation of the expensive and difficult logistics pipeline to Arctic communities may be further reduced leading to a return to subsistence living by native populations.

- The Russian Arctic is a storehouse of natural resources. Changing climate may spur an increase in exploitation of energy, mineral and forest resources, especially by or for the benefit of resource poor Asian nations.

- The response of marine resources to changing climate is very difficult to predict but northward migrations are likely. In particular, northward movement of Bering Sea species into the Beaufort/Chukchi Sea region north of Bering Strait is likely. Climate warming is likely to bring extensive fishing activity to the Arctic, particularly in the Barents Sea and Beaufort/Chukchi region where commercial operations have been minimal in the past. In addition, Bering Sea fishing opportunities will increase as sea ice cover begins later and ends sooner in the year.

- Ecological disruption due to climate-induced separation of essential habitats can be expected with particular effects on marine mammal populations.

- The exploration, development, production and transportation of petroleum in the Arctic will expand with or without climate change as prices continue to rise due to the decreasing rate of discovery of reserves elsewhere. Climate warming and reduction in ice cover will facilitate and perhaps accelerate the process.

- Energy shortages in the United States lead to accelerated exploitation of natural resources along the Alaskan Arctic Coast.

Modeling recent and future changes in the Arctic Ocean environment:

Understanding of global and regional components of the earth's physical environment and its short-to-long term variability is one of the main requirements for realistic forecasts of weather and climate. Both global climate models and recent observations suggest that the Arctic Ocean is the region where an amplified response to global climate change might be taking place. In addition, changes in the Arctic Ocean and sea ice circulation are important to dispersion of nuclear contamination, biological productivity, and navigational forecasts.

Some models predict that the Arctic ice will significantly reduce in area and volume or possibly disappear during summer months as a result of increased greenhouse gases. The sea-ice albedo feedback is used to explain such a scenario. It implies that at warmer temperatures there will be less sea ice in the Arctic, which will allow an increased absorption of solar radiation due to decreased albedo, which will result in even warmer temperatures, and so on. The only immediate stabilizing effect (or negative feedback) comes from more rapid radiative cooling of the sea ice surface at warmer temperatures. On the other hand, other stabilizing effects are possible over longer times. For example, warmer air temperatures may lead to enhanced hydrological cycle and greater moisture convergence into the Arctic Ocean providing increased stratification in the upper ocean. Melting of large amounts of sea ice must also lead to dramatic increases in the fresh water flux out from the Arctic Ocean. The Great Salinity Anomaly of the late 1960s and 1970s is a good example of such an extreme event.

An excess of fresh water exported from the Arctic into the Nordic and Labrador seas can alter or stop convection there, thus strongly affecting the formation of North Atlantic Deep Water and the global thermohaline circulation. The resulting effect on European weather is that Europe becomes more Canadian in weather, with severe damage to important crops such as grapes, and tensions heighten considerably. A favorable scenario of Arctic climate change is one with a shorter-term (years to decades) natural variability superimposed on the long term warming trend due to greenhouse gas and other human-related emissions. Such a scenario is at least partly in agreement with time series of the Arctic Oscillation (AO) and the North Atlantic Oscillation (NAO), which are often used as indices of Arctic climate variability.

Over the last few decades, general circulation models (GCMs) have made significant advancements in representation of physical processes determining oceanic regimes and their variability and in use of modern high performance computers to solve complex oceanographic problems. Regional models of the Arctic Ocean have increased their spatial resolution by an order of magnitude, from the order of 100 km to 10 km, during the last decade. As a result, many important (and commonly neglected) small-scale bathymetric and geographic features have been included in such models. This allows more realistic representation of circulation and water mass and properties exchanges within the Arctic Ocean and its interactions with the global ocean. High model resolution also allows to better address new tactical requirements of operational ice prediction models, such as ice edge position, lead orientation, and sea ice thickness and concentration.

Improved regional models can successfully simulate recent regime shift in the sea ice and ocean circulation between the 1970s / 1980s and the early 1990s. Model results are in qualitative agreement with hydrographic measurements (suggesting recent changes) from the SCICEX submarine cruises and from icebreaker expeditions in the early 1990s. One of the conclusions from those models is that changes in the sea ice and ocean circulation and properties are at least partly in response to larger scale variability in the Northern Hemisphere weather patterns, such as AO or NAO. The shelf circulation and shelf-basin communication changes significantly between different regimes. The large scale drift of sea ice and its properties as well as the fresh water export from the Russian shelves and the Atlantic Water circulation within the Eurasian and Canadian Basins change in the early 1990s. Largest changes associated with this shift take place in the Eurasian and Makarov basins, over the Chukchi/Beaufort shelves and slopes and in the Canadian Archipelago. Information about spatial distribution of recent changes is crucial as it provides guidance for future field campaigns and potential future tactical operations, not available otherwise. Results from both observations and models indicate that a continuation of large scale measurements including repeated basin-wide hydrographic transects and focused process studies in the above mentioned regions should be of highest priority. This would allow evaluation of what may be an inherent cyclicity in Arctic climate and understanding and possibly more reliable predictions of future climate change in the Arctic Ocean.

Climate Model Projections for the Mid-21st-Century Arctic:

The global climate models used by the Intergovernmental Panel on Climate Change (IPCC) project a stronger warming over the Arctic Ocean than over any other area of the Northern Hemisphere. However, the Arctic warming is highly seasonal, and it varies widely among the nine models used by the IPCC. Relative to the 1961-1990 baseline climatology, the central Arctic Ocean is projected to be warmer in the 2030-2060 period by 1-2 deg. C in summer (Jun-Aug), by 7-8 deg. C in autumn (Sep-Nov), by 8-9 deg. C in winter, and by approximately 5 deg. C in spring (Mar-May). The across-model standard deviation of the projected warming is nearly as large as the warming itself, ranging from 1-2 deg. C in the summer months to 5-6 deg. C in the winter months. The spatial pattern of warming over the subpolar seas and the Arctic Ocean is closely tied to the retreat of sea ice. Adjacent land areas are projected to warm more than the ocean areas in summer, but less than the ocean areas in winter.

Projected annual mean precipitation rates for 2030-2060 are generally higher than at present by about 1 cm per month, although the changes tend to be smaller in summer and larger in autumn. While there is a tendency for the largest precipitation changes to occur over the subArctic (50 deg.-70 deg. N), the spatial pattern of the projected change in precipitation is noisier than the pattern of temperature changes. The model-to-model scatter of precipitation change is even greater than the scatter of the temperature changes. Changes in evapotranspiration have yet to be evaluated.

Sea level pressure is projected to decrease by 1-2 mb over much of the Arctic. The largest projected decreases of pressure are in autumn and winter, and on the Eurasian side of the Arctic Ocean. While lower mean pressures may imply more cyclone activity, there has not yet been a systematic evaluation of daily model output to determine whether synoptic (i.e., storm) activity shows a significant increase in the climate scenarios. To our knowledge, there have been no evaluations of changes in cloudiness and radiative fluxes over the Arctic in the climate projections of global models.

Observed Climate Change in the Arctic:

Records for 1961-1990 over the central Arctic Ocean, collected as part of the Russian "North Pole" drifting station program, show statistically-significant increases in temperature of 0.89 deg. C and 0.43 deg. C per decade for May and June, respectively. Temperature increases during this period are also significant for summer as a whole. A different analysis for the period 1979-1997, based on a combination of temperature data from the North Pole program, drifting buoys and land stations, reveals statistically significant trends over most of the Arctic Ocean in spring, locally exceeding 2.5 deg. C per decade. This is consistent with indications based on satellite passive microwave records of an earlier onset of spring melt over the sea ice cover and is likely also related to reductions in sea ice extent of about 3% per decade since 1979 as assessed from satellite records.

Temperature trends over the Arctic Ocean are broadly consistent those over land. Land records show pronounced warming from about 1970 onwards (mostly in winter and spring), over Siberia and Northwestern North America. The general pattern of warming is partly compensated by cooling trends over eastern Canada and the northern North Atlantic. It is important to note that in terms of 55-85 deg. N zonal averages, temperatures around 1970 were below average. Hence, what we've really seen is (in part) a recovery from anomalously cold conditions. It also appears that from 1920-1940, Arctic temperatures rose even more sharply than in the past several decades. On the other hand, the paleo-climate records suggest that today's Arctic temperatures are the highest of at least the past 400 years, possibly longer.

Since 1900, there has been a general increase in precipitation for the 55-85 deg. N latitude band, largest during autumn and winter. There have been pronounced recent increases in the past 40 years over northern Canada. Changes over the Arctic Ocean are unknown due to the paucity of data.

The general pattern of recent Arctic temperature change and (at least to some extent) changes in precipitation appear to be related to shifts in the large-scale atmospheric circulation, reflected in generally positive modes of the Arctic Oscillation (AO) and North Atlantic Oscillation (NAO). Changes in the AO and NAO are also reflected in observed decreases on sea level pressure over the central Arctic, as well as a tendency for more frequent high-latitude cyclone activity. Recent modeling experiments indicate that anthropogenic forcing may modulate the intensity and frequency of modes of variability such as the AO and NAO.

In summary, observed changes in temperature, precipitation and atmospheric circulation are broadly in accord with climate model projections. However, attribution of change is complicated by the wide scatter between projections from different models.

A Scenario for Arctic Ocean Sea Ice in the Year 2050:

Predicting the future climate is risky. Climate is known to be variable on "all time scales." Trends that appear for, say, a decade may or may not persist into the next decade. Climate models make predictions based on an insufficient representation of important physics and chemistry. With this disclaimer, we construct a scenario for Arctic Ocean ice conditions in the year 2050. Our approach is this. We examined the changes predicted by four reputable global climate models. We compare these with extrapolated trends that have been observed over the last several decades. We then suggest a conservative interpretation of both types of evidence for what to expect by 2050. For both models and observations, we deal with end-of-summer minimal extent, volume and thickness, which have decreased more than winter maximums.

Model evidence: Four global climate models predict reductions in ice extent and thickness in the Arctic. The models all show a continually decreasing ice cover. A middle-of-the-road estimate from models is that by 2050, ice extent will be down about 30% (to 3.5 million sq. km).

Models also predict a declining ice volume. A moderate model estimate is that by 2050, ice volume will decrease some 40% to 5400 cubic km. Models are not fully credible. When run to "predict" past observations, different models show different biases, so their projections into the future are of uncertain validity. But they all predict a diminishing ice cover.

The 4-model average decrease by 2050 is 30% in summer minimum ice extent and 40% in summer minimum ice volume.

Observational evidence: The 100-year historical record from ships and settlements going back to 1900 shows a decline in ice extent starting about 1950 and falling below pre-1950 minima after about 1975. This decline is better documented by satellites during the last 20 years. The rate of decline is about 3% per decade.

The record of submarine ice draft data shows that the ice draft at the end of summer has declined by about 40% over a time interval of about thirty-five years, or about 11% per decade. There are few data from the intervening years, so it is difficult to assess "normal" climatic variability, even over the 35 years of submarine data, much less over a longer period.

Future scenario: A conservative scenario is that by 2050 the observed trend will reduce summer minimum ice extent by 15%; this is an extrapolation of the satellite observations which are quite reliable and are not contradicted by climate model forecasts. For volume and thickness, a conservative estimate is obtained by extrapolating model forecasts, which are not contradicted by sparse observations. By 2050, the end-of-summer volume can be expected to be down by about 40%, of which about 15% would be due to decreased extent and the remaining 25% would be seen in an end-of-summer thickness reduced by 25% to about 1.5 m.

What does this mean in terms of various regions of the Arctic? During winter, the central Arctic and all peripheral seas including the Greenland Sea, Bering Sea, and Gulf of St. Lawrence will continue to have significant ice cover. Extent and, in most areas, ice thickness will be reduced. The Sea of Okhotsk and Sea of Japan will be ice free for the entire year. In late summer, the entire Russian coast will be ice free, allowing navigation through the Barents, Kara, Laptev and East Siberian Seas along the entire Northern Sea Route. The Northwest Passage through the Canadian Archipelago and along the coast of Alaska will be ice free and navigable every summer by non-icebreaking ships. Ice will be present all year along the eastern and northern coasts of Greenland. Ice will also remain throughout the summer within and adjacent to the northern Canadian Archipelago. Significant ice will remain in the central Arctic Ocean, though the mean thickness will be about 1.5 m, and it will be less compact.

Changes in Weather Patterns in the Arctic under Assumed Global Warming:

Recent scenarios of climate change in the Arctic produced by state-of-the-art global climate models (GCMs) suggest that the Arctic/subArctic will see substantial warming over the current state. The cold season in particular in many models sees a 6-8 deg. C warming over the ocean, with a less dramatic change in terrestrial regions. Associated with many of these is the prediction of an ice- free or nearly ice free ocean state, at least seasonally if not throughout the entire year. It is certainly plausible that the marginal ice zone will migrate considerably poleward throughout the year in a warmer climate.

A discussion of how weather (vs. the cumulative effects of weather we call climate) is difficult to predict based on a broadly defined seasonal mean state. That being the case, it *is* possible to speculate on how weather as currently understood might be impacted by changes in a background "mean" state. Given the nature of Naval operations, this discussion will focus on marine weather

A more ice free ocean and/or longer ice free season would clearly lead to much greater latent and sensible surface heat fluxes into the Arctic boundary layer (BL). A warmer and moister BL would most likely produce greater BL cloudiness, perhaps extending the current observed summer cloud fractional coverage maximum on both ends of the warm season. This would result in poorer surface visibility for a greater portion of the year, and in the winter could also increase the likelihood of freezing mist and drizzle

Since the temperature of the continental Arctic away from the coastal regions will continue to be modulated largely by radiative energy loss (assuming that seasonal snow cover still pertains), the temperature differences between land and ocean will likely be more pronounced, creating more localized baroclinicity to the coastal regions in the cold season. Given the ingredients of greater baroclinicity, a BL environment with significantly enriched latent energy, and the strong planetary vorticity implicit in the high latitude setting, it seems reasonable for Arctic cyclogenesis of so-called polar lows to be more common than currently observed during much of the year.

BL-forced convection would be more likely with these systems, much of it being from mixed-phase clouds, particularly in the warm sector with higher precipitation rates and more localized precipitation. Vessel icing could be a prime concern, especially in the vicinity of cold Arctic continental air masses where over-running is likely to occur. With the likelihood of more mixed-phase precipitation through a much greater portion of the year, the threat of aircraft icing would also be greatly enhanced.

Under the ice free ocean scenario, the equator-to-pole temperature gradient will be diminished over current values perhaps weakening the magnitude of the polar jet. However, as stated above, the increased heterogeneity of surface heating in the lower troposphere may act as more of an "anchor" to the long wave pattern producing preferred regions of cyclonic storm activity and cyclogenesis.

Finally, the current tendency of poleward-propagating extratropical cyclones to decay in cooler subArctic waters (for example as currently happens in the Aleutians/Bering Sea and the
'coffin corner" of the Gulf of Alaska near Yakutat) might be diminished, causing stronger and more frequent activity in the subArctic coastal margins.

The Response of Arctic Hydrological Processes to a Changing Climate:

The effects of a warming climate on the terrestrial regions of the Arctic are already apparent; some subsequent impacts to the hydrologic system are also evident. It is expected that the effects and consequences of a warming climate will become even more pronounced within the next 10 to 50 years, at first primarily through atmospheric and near-surface processes and later through geomorphological evolution and hydrological responses to permafrost degradation. These changes will affect the Naval Mission in the Arctic Basin through impacts on regional weather, oceanic circulation patterns, salinity and temperature gradients, sea ice formation, and water properties. It is difficult to quantify the long-term effects of a changing climate, but it is possible to envision many of the changes that we should expect.

The broadest impacts to the terrestrial Arctic regions will result through consequent effects of changing permafrost structure and extent. As the climate differentially warms in summer and winter, the permafrost will become warmer, and the active layer (the layer of soil above the permafrost that annually experiences freeze and thaw) will become thicker. These simple structural changes will affect every aspect of the surface water and energy balances. As the active layer thickens, there is greater storage capacity for soil moisture, and greater lags and decays are introduced into the hydrologic response times to summer precipitation events. When the frozen ground is very close to the surface, the stream and river discharge peaks are higher and the baseflow (low discharge rates that occur in rivers between storms or in winter) is lower. As the active layer thickens and the moisture storage capacity increases, the lag time of runoff also increases. This has significant impacts on large and small scales. The timing of stream runoff will change, reducing the percentage of continental runoff released during the summer and increasing the proportion of winter runoff. This is already becoming evident in Siberian Rivers. As permafrost becomes thinner and is reduced in spatial extent, the proportions of groundwater in stream runoff will increase as the proportion of surface runoff decreases, increasing river alkalinity and electrical conductivity. This could impact mixing of fresh and saline waters, formation of the halocline, and seawater chemistry.

Other important impacts will occur due to changing basin geomorphology. Currently the drainage networks in Arctic watersheds are quite immature as compared to the more well developed stream networks of temperate regions. These stream channels are essentially frozen in place because the major flood events (predominantly snowmelt) occur when the soils and streambeds are frozen solid. As the active layer becomes thicker, there will be significantly increased sediment loads delivered to the ocean. Presently, the winter ice cover on the smaller rivers and streams (<~10,000 km^2) are completely frozen from the bed to the surface when spring melt is initiated. However, in lower sections of the rivers there are places where the channel is deep enough to prevent complete winter freezing. Break-up of the rivers differs dramatically in these places where the ice is not frozen fast to the bottom. Huge ice chunks are lifted by the flowing water, chewing up channels bottoms and sides and introducing massive sediments to the spring runoff. Such increased sediment loads may affect coastal water properties with consequent impacts on sound transmission, estuary productivity, contaminant transport, and a host of other marine processes.

As the air temperatures become higher, the active layer becomes thicker. Even if precipitation increases, we have reason to believe the surface soils will become drier. The Arctic is described in many basic geography textbooks as a desert due to the low precipitation rates; however, it is a desert that frequently looks like a bog as the ice-rich permafrost near the surface prevents infiltration of surface soil moisture to deeper groundwater. If the active layer thickens to the point where a talik (an unfrozen layer above the permafrost, but below the seasonally frozen soil) forms, then soils may drain internally throughout the winter leaving the surface significantly drier. As the surface soils dry, the feedbacks to local and regional climate will change dramatically, with particular emphasis upon sensible and latent heat flux. Drier soils will also influence the rate and intensity of tundra fires, providing more positive feedback mechanisms by creating darker surfaces that absorb more solar radiation and through releasing large quantities of carbon from peat soils. This may impact recycling of precipitation, military capabilities to predict weather and may indeed increase variability of many processes and variables, including convective storms.

These changes in the hydrological regime should improve productivity of terrestrial aquatic and marine ecosystems. Increases in winter baseflow will markedly improve winter habitat in streams and rivers for freshwater and anadromous fishes. There is a possibility that these rivers could eventually support commercial fishing industries. There are numerous economic and natural barriers constraining potential marine industrial development, however if the sea ice degradation does allow civilian vessels to work in the Arctic Ocean during at least the summer months, then we should expect a fishing industry will develop. As pressure on fishing resources continues to intensify throughout the North Pacific and North Atlantic, the fishing industry may indeed "push these limits" and attempt to establish market influence sooner than natural conditions permit. Consequently, Naval and Coast Guard rescues of vessels trapped in sea ice may become routine long before sea ice degradation allows extensive civil transport of the Arctic Ocean.

Arctic Environmental Change and the Northern Sea Route:

Recent Arctic environmental changes, in particular changes in the area and thickness of sea ice, can fundamentally impact Arctic marine transportation. Longer melt seasons, thinning ice covers, and reductions in multiyear ice have key operational implications (for example, greater access and longer navigation seasons) for shipping around the Arctic basin. Notably the Northeast Passage, or the Northern Sea Route (NSR) from a more formal Russian perspective, across the north of Eurasia has experienced reductions in the sea ice cover. In addition, the administration, regulation and overall operation of Russia's NSR have undergone considerable changes during the past decade following the end of the Soviet Union. The combination of regional environmental change and new management of the NSR and Russia's Arctic fleet pose potential implications for the United States and naval operations.

The end of the USSR has brought great change to all aspects of the NSR. Total cargo tonnage along the NSR has been reduced to less than 2.0 million tons, less than a third of what it reached during the heyday of the Soviet Union. This reduction in cargo and ship traffic is primarily a consequence of changes in the industrial complex at Noril'sk. However, year-round marine operations across the Kara Sea to Dudinka (port city for Noril'sk) were maintained throughout the 1990's. This was accomplished using the capable, but aging icebreaker fleet (nuclear and non-nuclear) of Murmansk Shipping Company (MSC). In November 1998 controlling interest in MSC was acquired by the Russian oil company, Lukoil; fresh capital from Lukoil has allowed the recent buildup of a domestic Arctic tanker fleet. Comprehensive and official regulations for navigation along the NSR remain in effect; navigation control, mandatory pilotage, mandatory icebreaker escort (in Vilkitskiy, Dmitry Laptev, Sannikov and Shokalskiy straits) and rules for escort represent a considerable effort to control domestic and foreign shipping along the NSR. Recent papers have highlighted the continued differences between the US and Russia concerning the NSR. The US continues to assert that the ice-covered straits of the NSR are international and subject to the right of transit passage; Russia continues to claim the straits as internal waters. This is likely to remain a contentious political issue between the US and Russia despite future access to the Russian Arctic under more favorable climatic conditions.

A comprehensive study of the NSR - the International Northern Sea Route Programme (INSROP) - was conducted during 1993-99 and funded primarily by Norwegian and Japanese interests. Three principal partners were involved: the Ship & Ocean Foundation (Tokyo), the Central Marine and Design Institute (St. Petersburg), and the Fridtijof Nansen Institute (Oslo), the key coordinator. The project produced 167 peer-reviewed working/technical papers (involving 318 researchers at 50 institutions in 10 countries; a handful of US researchers participated) and a comprehensive reference volume. Significant Russian information on the NSR environment, Arctic ship technology, legal positions, commercial shipping, navigation regulations, and regional (Russian Arctic) economies is now available outside Russia within the INSROP reports. The proceedings of an INSROP summary conference held in Oslo 18-20 November 1999 (The Northern Sea Route User Conference) have now been published. Included are several conclusions drawn from the conference and overall INSROP effort: the NSR's technological and environmental challenges are no longer absolute obstacles to commercial shipping; the EU and oil/gas interests are conducting pilot studies for Arctic marine routes between the Kara Sea and Europe; Russia needs to better accommodate the concerns and requirements of international shipping (NSR tariffs require considerable adjustment); and, the NSR's physical and operational infrastructure must be further developed to attract increased commercial use. Discussed during the workshop were the impacts of future reductions of sea ice along the NSR on extending the navigation seasons and future requirements for icebreaker support. One significant question remains unresolved: will future Arctic commercial ships navigate along the NSR independently (without icebreaker support) if ice conditions continue to improve?

Recent evidence from satellite observations confirms that the areal extent of Arctic sea ice has decreased approximately 3 % per decade. The largest decrease derived from historical records has been recorded for summer since 1950, a key observation for seasonal shipping along the NSR and other Arctic marginal seas. The Siberian Arctic has experienced sea ice reductions during the last decades of the twentieth century. Parkinson has shown regional sea ice reductions in the NSR area for 1978-1996: a 17.6 % decrease per decade in summer for the Barents and Kara seas, and a 3.7% decrease per decade for a large Arctic Ocean area including the Chukchi, East Siberian and Laptev seas. Record summer sea ice reductions in the Russian Arctic for

1990, 1993 and 1995 have also been identified; a record sea ice retreat was observed in 1998 for the Beaufort and Chukchi seas. The area of winter fast ice in the Russian Arctic (Kara Gate to Long Strait) decreased by 11.3% for 1975-93 and there have been reductions in total and old ice areas in the East Siberian Sea during 1972-94. Johannessen has observed a 14% decrease in winter multiyear ice in the central Arctic Ocean for 1978-98 and Rothrock has calculated ice thickness reductions (40%) from submarine data across the Arctic Ocean. These significant transformations and the regional trends noted for the Siberian Arctic, if continued, portend improved conditions for Arctic navigation along the NSR.

Several implications for the US/USN are apparent with regard to the changing nature of Russia's Northern Sea Route:

- Potential greater marine access along the Russian Arctic coast for domestic and international commercial shipping;

- Continued US and Russian differences in the application of the LOS to the Arctic and NSR;

- Closer collaboration between the EU and Russia in development of Western Siberia by oil/gas interests and use of the NSR as a regional marine route (between the Kara Sea and Europe);

- Potential use of the NSR for through transit (Atlantic to Pacific and return) of hazardous wastes and other sensitive cargoes;

- Lukoil's dominant position as owner of both icebreakers and Arctic tankers, and the exclusion of other domestic & foreign competitors (for example Finnish tankers);

- The continued exclusion of US research ships from operating in the Russian Arctic for collaborative science.

Climate change in the arctic: Effects on Sonar Performance

Background: Recent reports indicate a dramatic decrease, over the past several years, in sea ice thickness and extent in the Arctic. If this trend continues, significant areas of the Arctic Ocean may become permanently ice free in the future. The entire area may become seasonally ice free. The presence of sea ice has great impact on Naval operations. In particular, it affects the performance of sonars, and it makes the region a parochial submarine operating area.

Discussion - The present situation: Near-surface sound propagation paths in the central Arctic are typically upward refracted, due to a positive sound velocity gradient; such upward refraction traps acoustic energy near the surface, and results in abnormally low long-range propagation losses at low frequencies (below 50 Hz.) The presence of ice cover causes the sound propagation to be dispersive; higher frequencies suffer greater losses due to multiple reflections off the rough under side of the ice.

- Ambient noise in the Arctic can be extremely low (lower than sea state zero) in the central Arctic under solid ice cover; or extremely high in marginal ice zones, where the noise of collisions from moving ice can exceed that of wave noise in the open sea.

- Ice keels, created as sea ice is compacted by wind and currents, present large acoustic reflectors to active sonars; they can easily equal or exceed the acoustic target strength of a large submarine.

- The geographic proximity of the Arctic Ocean to North America, Europe, and Asia makes it a particularly attractive area for the stationing of strategic (ballistic missile) submarines. Transiting submarines may be detected at long range by surveillance sensors, but the ice canopy makes deployment of surveillance systems costly and difficult. Stationary submarines can take refuge near the ice, where they are virtually undetectable and invulnerable to attack; or in the marginal ice zones, where environmental noise masks their presence.

- Operation of submarines in shallow ice-covered seas is especially difficult and hazardous due to the need for the submarine to operate close to the ice where ice keels present collision hazards. Active sonar must be used continuously in such environments (contrary to the instincts of submariners) in order to assess ice hazards ahead of the ship. ASW operations, concurrent to a shallow under-ice transit, are impossible as the ship is fully engaged in navigating the ice hazards.

Probable changes due to climate change: Melting of Arctic sea ice will expose the sea surface to winds, which will significantly change both ambient noise and acoustic propagation. Wind-generated waves will make ambient noise in the central Arctic more typical of temperate oceans (i.e., increase). Wind-generated mixing of near surface water, combined with warmer air temperatures, will diminish or eliminate the surface duct, increasing low frequency propagation loss.

Disappearance of the ice canopy will also eliminate the haven now provided to stationary submarines by ice keels. Active sonar detection of submarines, both by ASW sonars and by acoustic torpedoes, will become feasible.

In summary, melting of sea ice in the Arctic will turn it into a conventional open-ocean ASW environment, with none of the advantages it now affords to an adversary strategic submarine.

In spite of the increased vulnerability to a strategic submarine positioned in the Arctic, because of its geographic location it will still be a prime location for stationing such forces. And, perhaps significantly, absence of sea ice will render the ocean both accessible to and a viable operating area for any submarine force B ice strengthened or not; nuclear or conventional.

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